Emergency Pipeline Repair Systems (EPRS) – Are you ready?

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Recent advancements in isolation technology to facilitate the repair of unpiggable defects

Despite good pipeline design and integrity management schemes pipelines can and do get damaged and need to be repaired. The damage could be caused by dragged anchor / landslide / iceberg / fatigue / stress cracking. The damage may be unpiggable (Buckle / Dent) with or without line rupture.

Figure 1: Unpiggable Defect in Pipeline

Following inspection and defect assessment, repair may require replacement of a section of pipeline.

Figure 2: Cut Out Damaged Section of Pipeline

Without suitable double block isolation tools installed locally at both sides of the damaged section; it will be necessary to flood and depressurise the pipeline to allow safe removal of the damaged section and perform the repair by installing a new section. The new section could either be welded in or connected to the existing pipeline with weldless mechanical connectors.

Depending on availability of emergency repair equipment the time to return a pipeline to service could be more than 1 year. However, with appropriate planning and investment in equipment, including isolation tools and procedures this could be reduced to approximately 6 weeks.

1. Recent Pipeline Damage Incidents

Some examples of large diameter pipeline incidents in last 5 years: (excl. GoM)

- 36" CATS trunk line
- 26" Kvitebjorn line
- 2 off 24" North Africa lines
- 30" ADMA Oil export line
- 20" and 26" Trans-Med. Lines

It took at least 12 months from the time of incident until normal operations were resumed (except CATS).

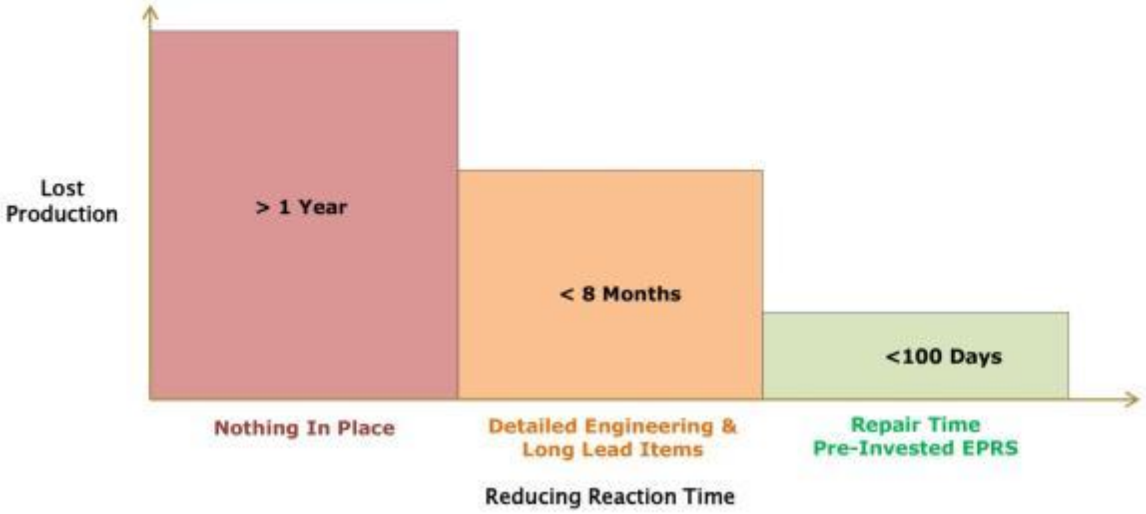


Figure 3: Reducing Reaction Time – Planning and Investment

A pipeline's out of service time, following an incident, can be reduced with strategic investment in specific elements of an Emergency Pipeline Repair System (EPRS).

The time to repair can be reduced from more than a year to somewhere in the region of 6-8 months, with some initial investment in an Emergency Pipeline Repair System. Developing detailed procedures for potential repair scenarios

and procurement of long lead items; such as large forgings for clamps/mechanical connectors, replacement pipe and flanges will reduce the reaction time.

Further substantial time savings can be achieved if the EPRS equipment has been manufactured and is kept in a state of readiness for emergency deployment. Potentially reducing a pipeline's out-of-service time to less than 100 days.

Even with an Emergency Pipeline Repair System in place, if suitable isolation tools are not available the time from incident to resumed production can be over 3 months. The decommissioning (flooding and depressurising) and re-commissioning (leak testing / dewatering) stages will be a significant proportion of the out-of-service time, this could potentially be more than 60% of the downtime, as illustrated in the following emergency pipeline repair timeline.

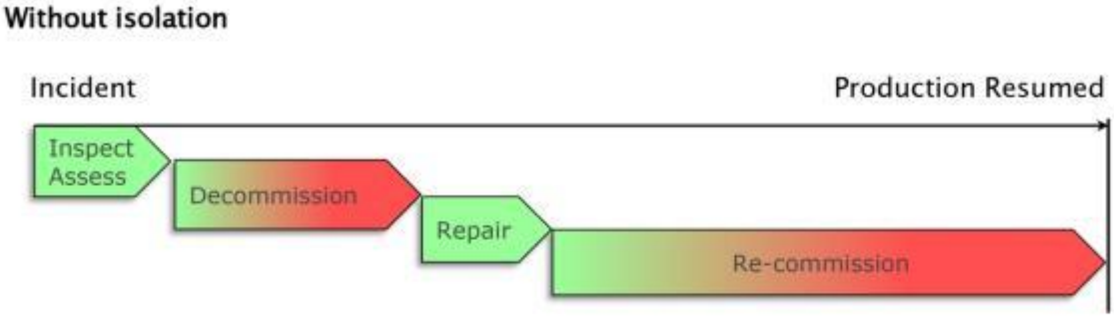


Figure 4: Emergency Pipeline Repair Timeline – Without Isolation Tools

If isolation tools are available as part of the Emergency Pipeline Repair System, the pipeline return to service time will be reduced, potentially down to less than 6 weeks.

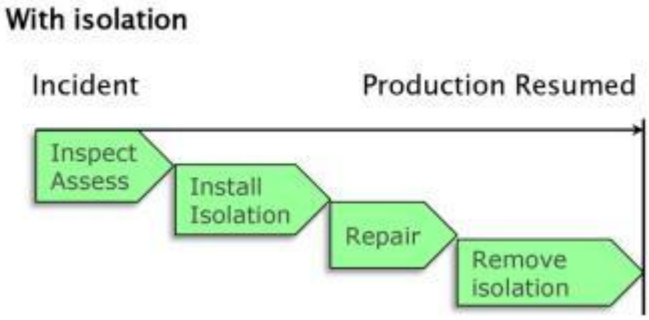


Figure 5: Emergency Pipeline Repair Timeline – With Isolation Tools

2. Emergency Pipeline Repair Isolation System – Benefits

- Safer worksite / Reduced inventory losses
- Minimal discharge to environment
- Prevents seawater ingress – Dewatering not required
- Time to repair reduced - Pipeline's "Out of Service" period is minimised

3. Double Block Isolation Tools Options For Unpiggable Pipeline Defects

3.1. BISEP™ Double Block & Bleed Isolation:

The BISEP™ is not the main subject of this paper but it is included as an isolation option because in certain circumstances it will be the most appropriate isolation tool, as briefly described below.

In some cases, due to lack of pig launchers or receivers or the presence of previous dents, a pipeline may not have been piggable even before it was damaged. Also, if the line has not been pigged, cleaned or inspected to provide sufficient confidence that an isolation tool can be pigged to the defect location; the risks of deploying a piggable isolating tool may be deemed too high.

In this situation, a damaged section of pipeline can still be removed safety without having to depressurise and flood the entire line, by using double block and bleed Isolation tools that can be installed into a pipeline via a single full bore hot tap penetration – requiring only one penetration for each double block and bleed isolation.

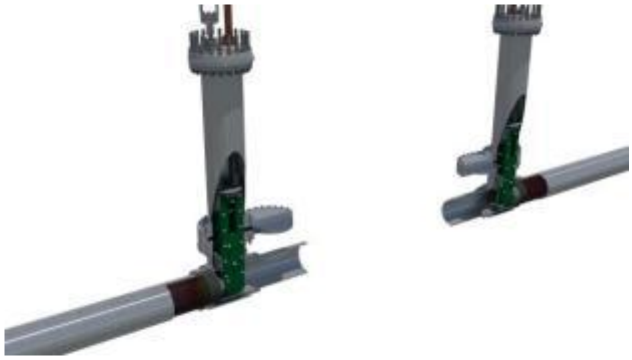


Figure 6: BISEP™ Double Block & Bleed Isolation Tools Installed for Sectional Replacement

A BISEP™ may be required to allow installation of temporary or permanent launcher and receiver so that a piggable isolation tool can be deployed into the pipeline.

3.1.1. BISEP™ Description

The BISEP™ (Branch Installed Self-Energised Plug) key components are a spherical sealing head, clevis arm retention, and a pressure competent launcher. The tool is hydraulically operated with fail-safe actuation (self-energisation) via the pipeline pressure differential.

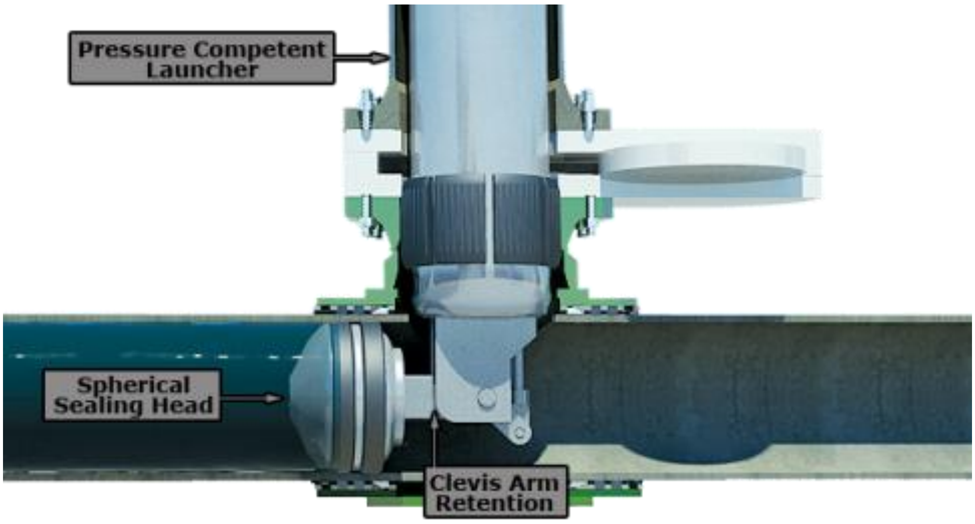


Figure 7: BISEP™ Key Features

The BISEP™ is housed in the pressure competent launcher tube. The launcher tube facilitates testing of the sealing head integrity prior to deployment. This launcher is connected to the hot tap valve and pressure tested. STATS standard procedure is to pressure test this assembly against the closed valve with inert fluid (water or Nitrogen) although on a well-ventilated site this could be performed with pipeline fluid using the pressure equalisation valves on the hot tap valve.

Figure 8: 30in BISEP™ Installation

Inside the launcher tube is the sealing head and clevis arm assembly. The deployment cylinder on the launcher drives the spherical head through the hot tap penetration into the pipe where it is rotated 90 degrees, towards the pressure threat. At this time the sealing head is unset so there is sufficient clearance between the head and the pipe bore to allow pipeline fluid to bypass. The tool can therefore be deployed into a flowing line.

Figure 9: BISEP™ Set Sequence

The rotation of the sealing head is done hydraulically to ensure full control. The spherical shape of the head ensures that it can rotate freely inside the pipe while retaining the radial clearance for potential pipeline flow. The pipeline flowrate is limited by the hydraulic force in the rotation cylinder and the current standard design accommodates standard acceptable flowrates for the hot tapping operation. Higher flowrates can be accommodated with prior notice during the design stage. Head rotation orientates the reaction shoulder against the clevis arms.

Once the head is fully rotated, the seals can be activated. Initial activation is provided by the internally mounted hydraulic cylinder. This axially compresses the two seals, the resultant radial expansion causes them to compress against the pipe wall, creating the seals. This will provide an isolation of the pipe and any flow will be stopped. The gradual setting process of the seals ensures a controlled flow termination.

The boundary, once established, offers dual leak tight barriers. The annulus between the seals can be pressurised, or depressurised to test the seals. The testing of the dual seals are performed in the isolating direction, this requires the isolated section to be vented to ambient. Thus on a mid-line isolation, both BISEPs™ at either end of the isolation require to be installed and set prior to the isolation being verified. This pressure venting can be performed using the BISEP™ launcher vent ports as the BISEP™ hot tap penetrations are in the isolated zone.

3.1.2. Double Block Verification

Once the isolated section is vented, the BISEP™ has full pressure differential across it. The annulus between the seals will be slightly above the pipeline pressure due to the seal compression reducing the volume of this void. This annulus void is piped through the launcher to give external access which allows the pressure to be raised, if required, to ensure a suitable differential pressure can be locked in for the secondary seal test. Holding the annulus above the pipeline pressure ensures no fluid can pass from the pipeline to the annulus during the secondary seal test.

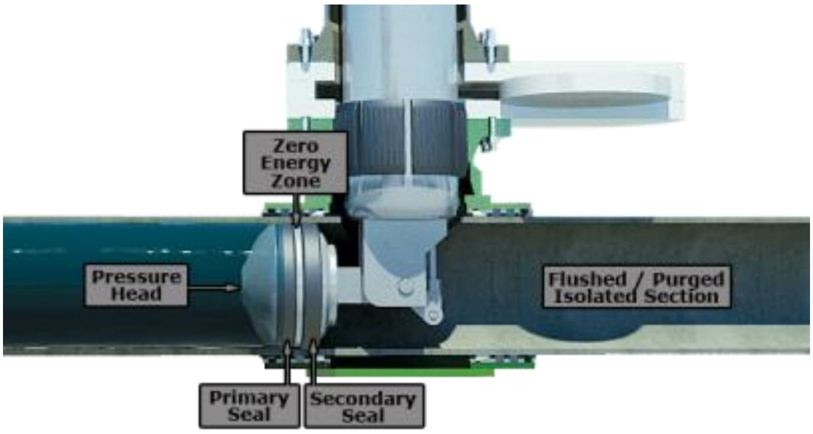


Figure 10: BISEP™ Double Block Verification

3.1.3. Secondary Seal Integrity Test

With pressure locked in the annulus the pressure behind the BISEP™ is vented to ambient, the BISEP™ secondary seal is isolating full pipeline pressure in the correct, isolated, direction. This condition is locked in to prove the secondary seal.

3.1.4. Primary Seal Integrity Test

Once the secondary seal has been verified, the annulus between the seals is vented to ambient using the external piped connection. The vented annulus is then locked in and monitored for pressure build out. At this time the full pipeline pressure is held by the primary seal proving the BISEP™ primary seal in the isolated direction. Once tests are complete, the annulus is left locked in and monitored for the duration of the isolation.

3.1.5. Self-Energisation

A vital safety feature of the BISEP™ is self-energisation (self-locking), where the differential pressure across the BISEP™ head generated by the isolated pipeline pressure retains the seal activation independent of the hydraulics.

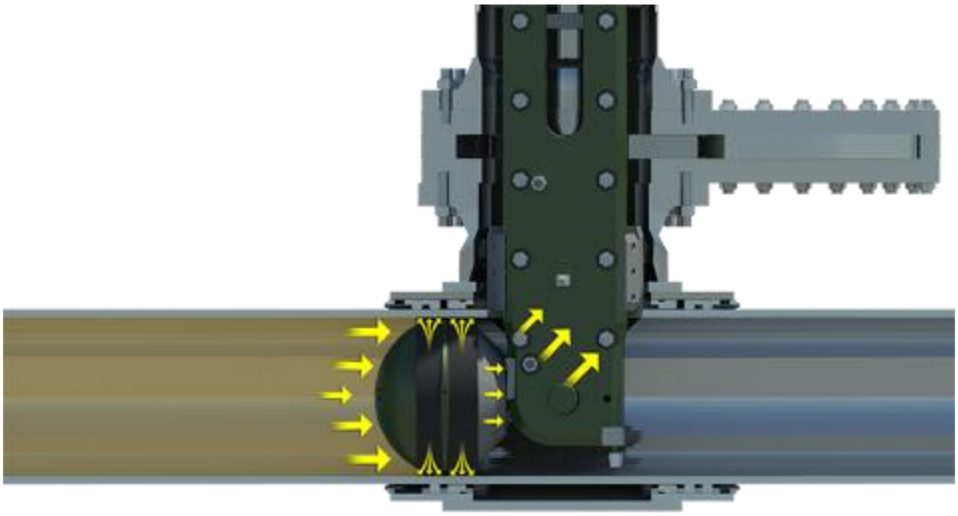


Figure 11: BISEP™ Self-Energisation

The axial movement of the pressure head is retained by the seal and, once fully constrained by the pipe bore, the compressed seal generates a contact pressure and can be assessed as a fluid for load calculations.

The pipeline pressure acts on the whole pressure head, generating an axial force towards the seal. An axial load balance across the head shows that the rubber pressure times the radial cross sectional area of the seal contact with the head must equal the load generated by the pipeline pressure. The annular nature of the seal ensures that the seal contact area is significantly less than the disc area of the head so the rubber pressure in the seal is held above that of the pipeline pressure. This has two benefits. Firstly the pipeline pressure can't pass a seal at higher pressure and secondly this high rubber pressure is highly compliant to pitting, seam welds and poor pipe bore condition. The self-energisation pressure from the pipeline pressure must be sufficient to overcome the initial load to compress the seal out to the pipe wall. This load is defined as the self-energisation pressure, which is the minimum differential pressure across the tool which will maintain the seal in the case of total loss of hydraulic pressure and normally in the region of 10 bar (150 psi).

This axial load then acts on the annulus ring which in turn is retained axially by the secondary seal. Thus the secondary seal is pressurised by the differential across the sealing head in a similar manner to the primary seal. The secondary seal is retained by the seal support head which is a leak tight head equivalent to the pressure head. This seal support head bears on two solid clevis arms, each one capable of taking the full load. The clevis arms are axially retained by the hot tap penetration and fitting.

The assessment above is simplified and does not take account of the hydraulic actuation load which is additional to the differential pressure load. This hydraulic set load is retained and monitored during the isolation to ensure that a loss of pipeline pressure would not result in a loss of either barrier.

3.1.6. Isolation Monitoring

During the period of isolation the following circuits can be monitored:

- Annulus between the seals
- Hydraulic set
- Hydraulic unset (normally vented)
- Body vent – this is the cavity inside the core of the spherical head

Any change in the status of the isolation would cause a change in these circuits which would provide sufficient warning to either address the change or clear the worksite.

The connection to the annulus does provide the ability to vent any rise in annulus pressure in a similar manner to a double block and bleed valve.

On top of this ability, there is the ability to raise the hydraulic set pressure if required to improve the seal, or reduce the hydraulic pressure to reduce the load on the seal.

3.2. Tecno Plug™ Description

- Piggable Double Block and Bleed (Dual Seal) mechanical isolation plug
- Plug module provides dual sealing and locking function
- Control module houses the hydraulic and electronic circuits to set, unset and monitor the isolation tool and pipeline pressure
- The remote control module is an ATEX rated pressure vessel
- The control module communicates through the pipe wall using ELF communications

Figure 12: 36" Remote Tecno Plug™ Deployment Malaysia

3.2.1. Double Block Isolation

- Both seals are fully tested at isolation pressure
- Both seals are dual energised (isolated pressure and hydraulic control system)
- Pressure is not trapped between the seals during isolation

3.2.2. Double Block Verification - Seal Testing Sequence

Prior to setting the plug the pipeline pressure will be equal on both sides of the plug

Figure 13: Pressure Equalised on both sides of Plug

3.2.3. Secondary Seal Verification - Full Differential Pressure Leak Off Test

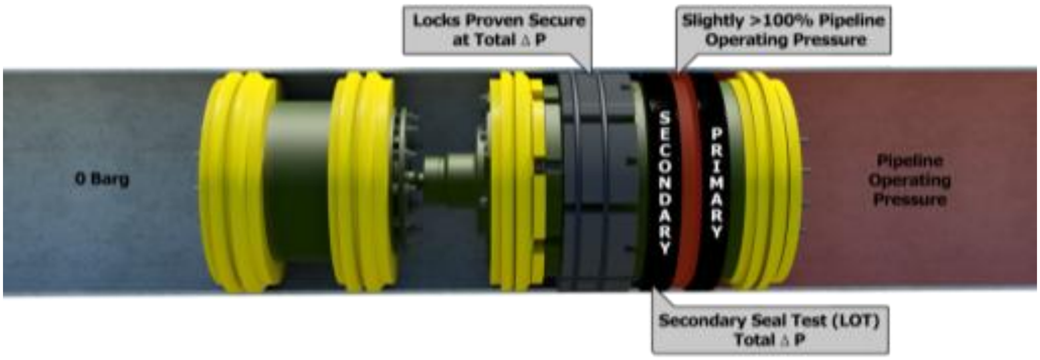


Figure 14: Secondary Seal Test

1. Plug confirmed set once slight increase in annulus pressure
2. Upstream pressure vented to ambient at
3. Plug engagement with pipe wall confirmed by plug position monitoring
4. During secondary seal test annulus pressure slightly above pipeline pressure
5. Annulus pressure between seals is monitored for pressure leak off
6. Secondary seal integrity proven with full differential pressure

3.2.4. Primary Seal Verification - Full Differential Pressure Build Up Test

Figure 15: Primary Seal Test

Upon completion of secondary seal verification test:

1. Vent annulus pressure to ambient (small volume vented to upstream side)
2. During primary seal test annulus pressure vented to ambient and pipeline pressure is at full isolation pressure.
3. Annulus pressure between seals is monitored for Pressure Build Up
4. Primary seal integrity proven with full differential pressure
5. Throughout isolation period a Zero Energy Zone is provided between two fully proven seals.

3.2.5. Self-Energisation - Isolation Failsafe Feature

Self-energisation (self-locking) feature maintains safe isolation while differential pressure exists across the tool. The isolation plug has two separate activation mechanisms:

1. Both seals and locking grips fully energised by pipeline pressure
2. Both seals activated and locks held in place by the integral hydraulics

Both separate activation mechanisms need to be removed to unset the plug

Figure 16: Tecno Plug™ Self-Energisation

3.2.6. PASSIVE UNSET: Fail-Safe Unset and Recovery Feature

In the unlikely event of control system failure or possibly flat batteries, the Passive Unset feature ensures the Tecno Plug™ is always recoverable upon job completion. The hydraulic system override releases the tool setting mechanism when pressure is equalised. The plug will then passively unset – without any active control input. Isolation cannot be unset until the breaking containment operation is completed and the pressure behind the plug is raised to pipeline isolated pressure. If the pressure is equalised, the plug will become unset <u>unless</u> it is actively commanded not to unset. The passive unset is done in a safe and controlled manner only when the pressure is equalised across the tool.

3.2.7. Communication and Monitoring

The remote control system provides a high degree of flexibility and eliminates the need for hydraulic control tethers or specially modified pig-trap doors. Through-wall communication is achieved using an extremely low frequency (ELF) communication system for reliable tracking and accurate positioning of the Tecno Plug™. The onboard sensors, hydraulic power pack, communication and control modules provide the necessary actuation, control and monitoring functions for the tool. The remote control module is ATEX rated and provides a robust system for safety critical activities. The communication system has undergone rigorous validation testing and has an extensive track record of successful live deployments.

For subsea isolations, communication is done via a through-water acoustic link or with a direct cable link. For wireless communication a subsea deployment frame containing the ELF antenna, subsea acoustic modem and batteries is deployed outside the pipe adjacent to the Tecno Plug™ within the pipeline and the two way data link is maintained via a hydrophone deployed from the vessel.

Using the wireless through-water acoustic system is suitable for deeper water applications or when the surface vessel is not necessarily working at the isolation plug location. In shallower water (less than 150m) and when the working surface vessel is located in close proximity to the isolation plug position then use of the direct cable down line is suitable.

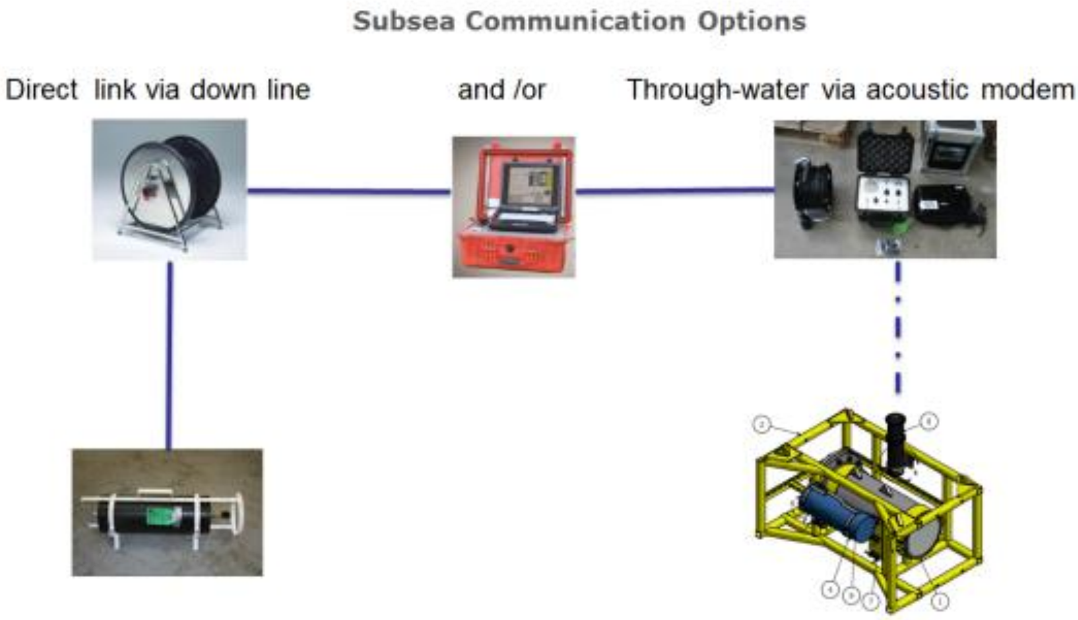


Figure 17: Subsea Communication System

4. Case Study: EPRS Isolation Tools - For QatarGas

Figure 18: EPRS – Isolation Tecno Plug™

4.1. Introduction

Client is developing an EPRS to cover their five major gas pipelines. In total, 380km of pipeline and a maximum field water depth of 60mtrs.

Much of the EPRS has been defined including the pipe repair specification and STATS were requested to develop the isolation aspect of the EPRS.

An engineering study was commissioned on the basis that any one of the pipelines had sustained anchor damage sufficient to create a bore restriction of up to 10%. (defined by ILI tool limit)

The engineering brief suggested straddling the defect area with a pair of Tecno Plugs™ launched in tandem from the platform to allow the defect to be cut out without flooding the line.

4.2. Engineering Assessment - Defect Negotiation

For any Tecno Plug™ scope, a consistent process is followed to assess the deployment of a Tecno Plug™ into a pipeline, application of the isolation and its subsequent recovery. As the study covered five individual pipelines, a Design Premise was generated for each pipeline (launcher to receiver). Further to the Design Premise, the piggability of each pipeline is assessed to ensure the full pipeline can be negotiated and what equipment would be required to facilitate this. (At this stage the proposed damaged area was not considered). With all of this data and assessment now completed, the effects of the anchor interaction could now be included into a deployment assessment.

4.3. Defect Negotiation

Although the study remit was to negotiate a bore restriction up to 10%, a range of pipeline displacement scenarios also had to be considered.

- 2% pipeline strain - equivalent defect radius of 24D Bend
- 4% pipeline strain - equivalent defect radius of 13D Bend

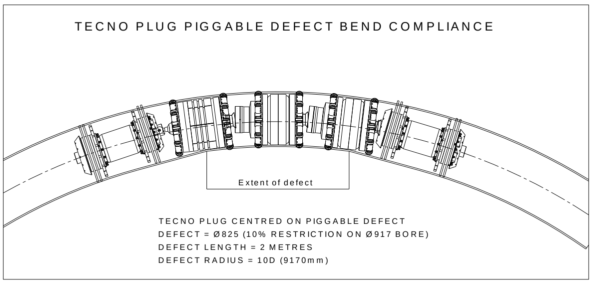


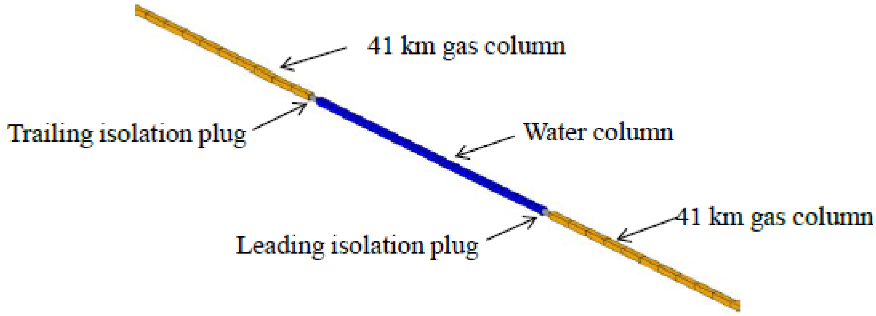
Figure 19: Displacement Scenario

4.4. Flow Modelling of Tecno Plug™ Train

One area of concern with the proposed Tandem Plug Train was the action of the leading Tecno Plug™ as it negotiated the defect. What level of controllability could be maintained over the plug train? Could the plug train be accurately positioned at the defect area? Early discussions had included utilising flow modelling software to ‘predict’ plug behaviour at the defect.

4.4.1. Flow Model – Approach

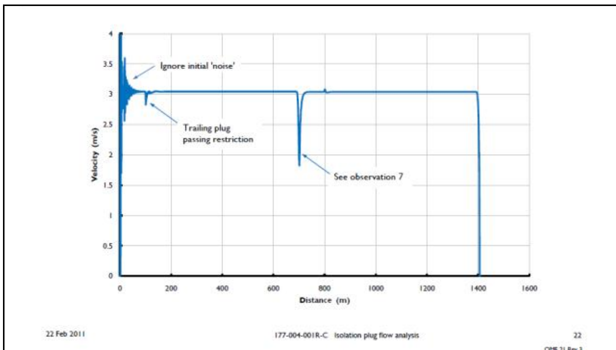
- Create an Abaqus / Explicit finite element model of the entire 80km pipeline containing a single defect, the production gas and pigged isolation plug train
- Represent the water column with linear Us – Up Hugoniot equation of state material model
- Represent the gas columns with an ideal gas equation of state material model



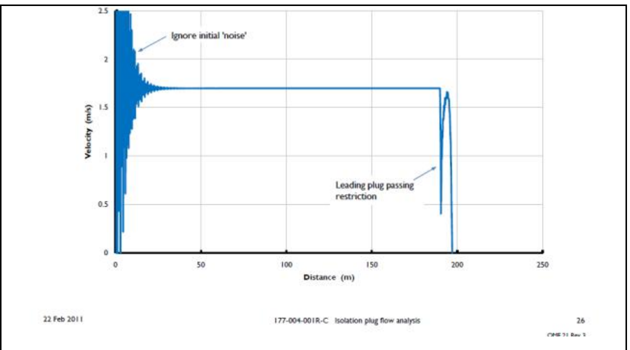
4.4.2. Simulation Cases

Run	Water column length [m]	Water/condensate column length [m]	Initial velocity [m/s]	Lead plug starting position [metres before reaching 10% diameter restriction at start of simulation]	Restriction length [m]
1	100	N/A	0	Lead plug pushed through restriction from rest	0.5
2	100	N/A	1.3	90	0.5
3	50	N/A	1.7	190	0.5
4	100	4000	1.0	245	0.5
5	100	1000	1.0	140	0.5

All simulations start at the instant that the control valve is shut
Initial velocity for runs 2 and 3 is the minimum velocity at which the lead isolation plug will penetrate a 10% diameter restriction
Lead plug starting position is an approximated value to carry out each simulation. Refer to the results for adjusted values



Flow Model – Run 1



Results – Run 3

4.4.3. Tandem Plug Train Operation – Conclusions

The results of positional accuracy changes considerably by adjustment of the variables. Tecno Plug™ tracking to defect location is critical to ensure approach velocity is correct and signalling to stop pumping operations is very time critical. When dual phase flow is introduced, the theoretical model appears to become 'confused' suggesting alternative software may be more suitable to the case. Overall, based on the outcome of the flow modelling, another, more controllable method of deployment was considered and explored.

4.5. Pigging From Both Ends

Approaching the defect from both sides was identified as the preferred solution. We have performed similar operations previously but not on such a large scale and the vent process was different. Similar hardware had been used before but for a different function. The client's field design meant that reverse flow could be re-routed at certain points. If this facility was not available, we could reduce pipeline pressure and pig towards the platform until we reached the upper pressure limit and then vent through to the back of the Tecno Plug™.

4.5.1. Functional Specification

- Double block and vent facility
- Independent locking and sealing mechanisms
- Flow bypass facility
- Both seals fully self-energised and tested
- Zero energy zone in the seals annulus (no trapped pressure)
- No single mode of failure

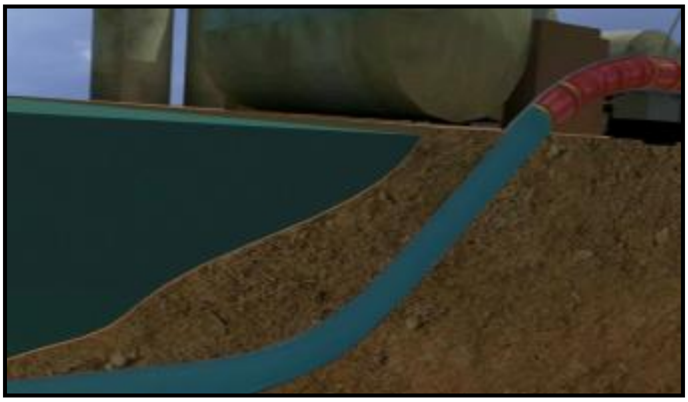
5. Isolation Tool Development

Tecno Plugs™ have be developed (designed, manufactured and qualified) that can be pigged towards an unpiggable line defect – from both sides or to pass through a dent (less than 10%). So that a double block isolation can be installed at both sides of the damaged section.

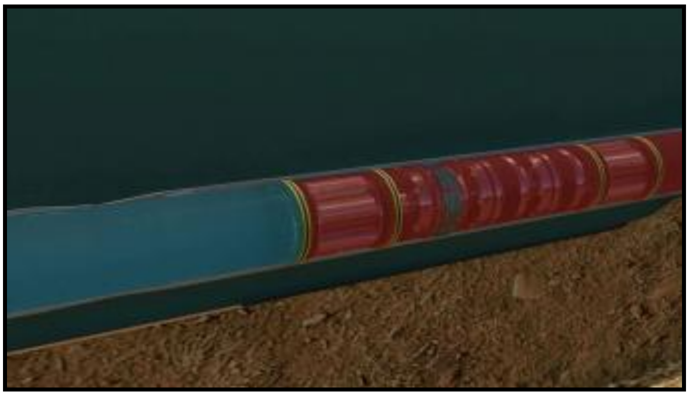
Figure 20: EPRS Specific Tecno Plug™ Incorporating Bypass Facility (patent pending) Isolation Plugs for 32” 34” 38” Pipelines (Two plugs for each line)

5.1. Pigging Towards An Unpiggable Defect From Both Ends

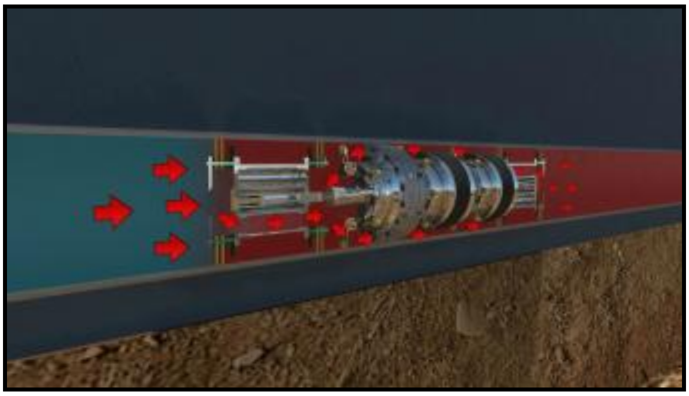
The EPRIS Tecno Plug™ was developed to allow two Tecno Plugs™ to be pigged from either end of a piggable pipe towards an unpiggable defect. The first plug can be pigged to location then the locks are activated and bypass valves opened. The second plug can then be sent towards the pre-installed plug with the pipeline fluid being displaced through the bypass valves on the first plug. This enables one plug to be located at each side of the damaged section needing to be removed. The following sequence of images describes how this is achieved.



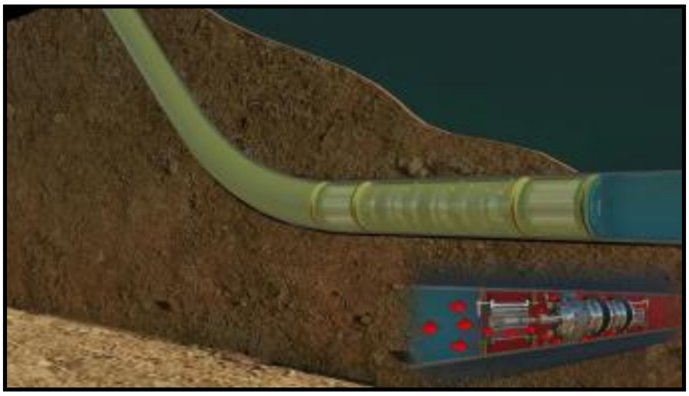
First plug is deployed from one end of the pipeline toward the defect.



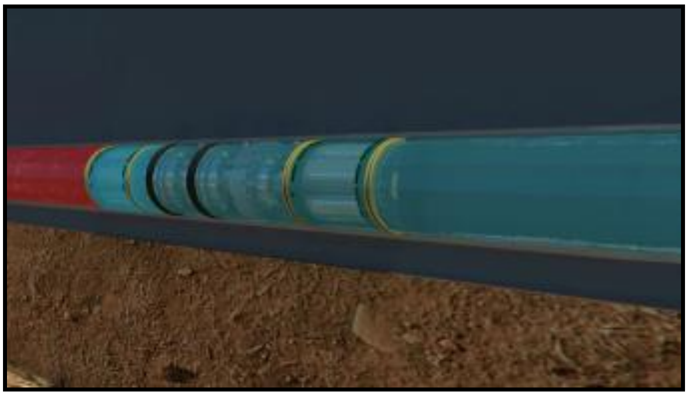
Before reaching the line defect the plug is partially set (locks only) and the through port vent opened.



Opening the through port allows the second plug to be pigged from the other end of the pipeline - towards the first (partially set) plug.

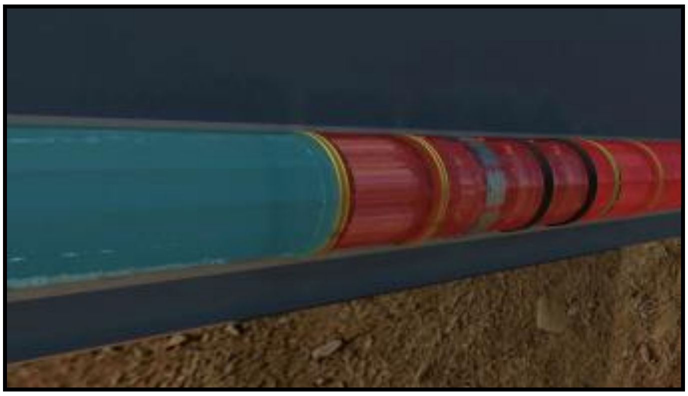


As the second plug is pigged, the product between the plugs passes through the partially set first plug.



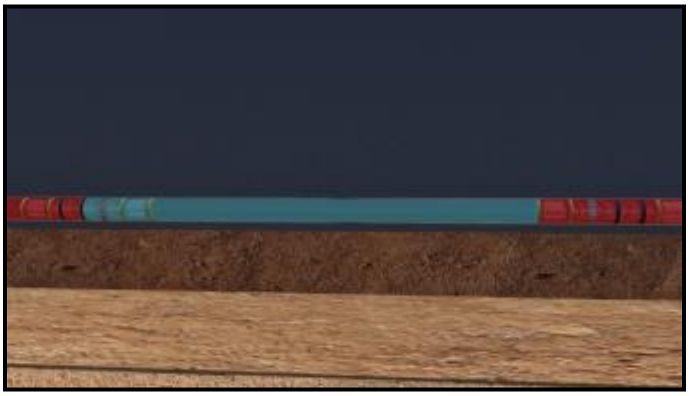
Once both plugs are at the desired set location.

Second plug is fully set (locks and seals).



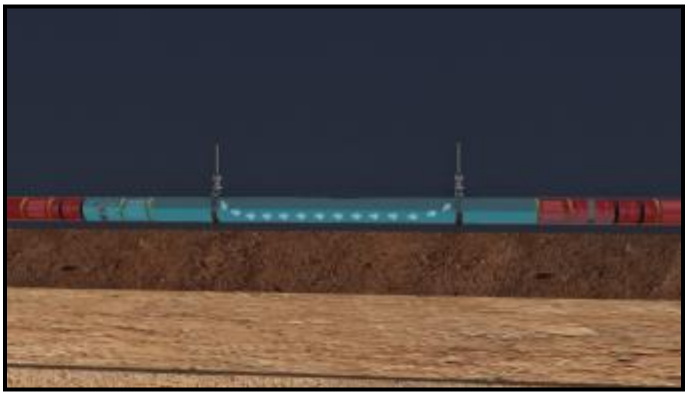
The first plug is then fully set (seals compressed onto pipe wall).

Through port (bypass) valve is closed.



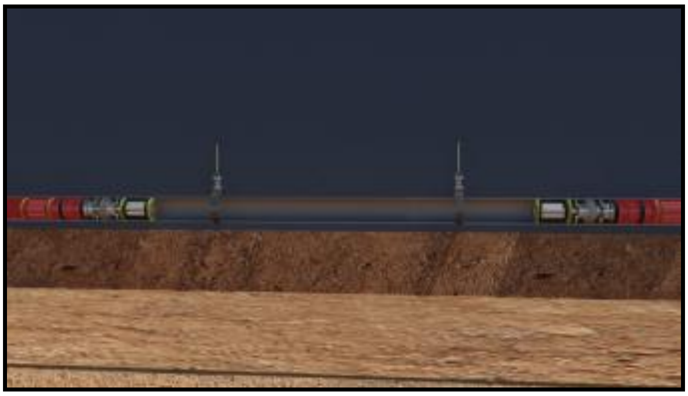
The damaged section of pipeline is now isolated.

Double Block Isolation of both plugs is proved.



Lightweight Hot-tap Clamps fitted.

The isolated area is flushed from one end and vented from the other.



The Isolated section is then fully vented to (subsea) ambient.

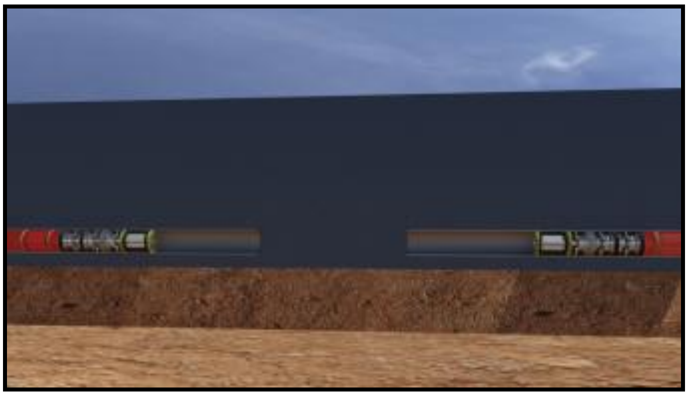
Pressure between the seals is monitored to prove the Secondary seal.

Seal tested with full pressure in the correct direction.

The annulus between the seals is vented to produce a zero energy zone.

Pressure build up test of annulus proves Primary seal isolation.

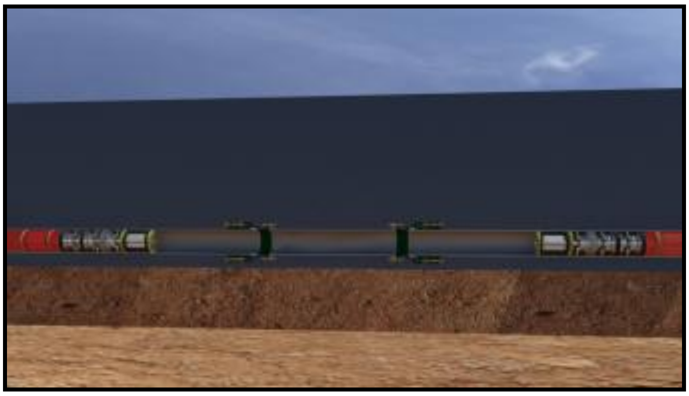
Seal is tested with full pressure in correct direction.



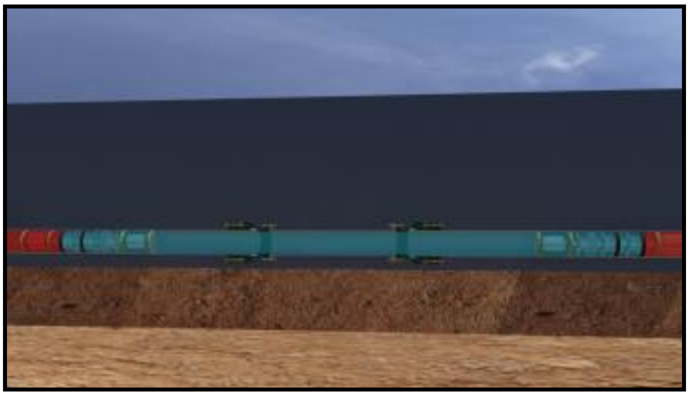
Pipeline repair work is carried out.

Line is not flooded, inventory is not lost.

Environment is not contaminated.

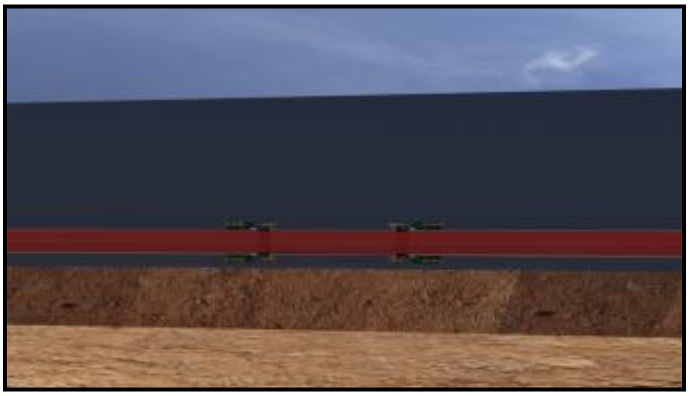


New section of pipe installed using mechanical connectors or hyperbaric weld.



Leak test the repair.

Equalise pressure and unset both plugs.



Pig both plugs back to one end of the pipeline and remove from receiver.